

*WITHIN-SESSION RESPONSE PATTERNS ON CONJOINT
VARIABLE-INTERVAL VARIABLE-TIME SCHEDULES*

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Operant responding often changes within sessions, even when factors such as rate of reinforcement remain constant. The present study was designed to determine whether within-session response patterns are determined by the total number of reinforcers delivered during the session or only by the reinforcers earned by the operant response. Four rats pressed a lever and 3 pigeons pecked a key for food reinforcers delivered by a conjoint variable-interval variable-time schedule. The overall rate of reinforcement of the conjoint schedule varied across conditions from 15 to 480 reinforcers per hour. When fewer than 120 reinforcers were delivered per hour, the within-session patterns of responding on conjoint schedules were similar to those previously observed when subjects received the same total number of reinforcers by responding on simple variable-interval schedules. Response patterns were less similar to those observed on simple variable-interval schedules when the overall rate of reinforcement exceeded 120 reinforcers per hour. These results suggest that response-independent reinforcers can affect the within-session pattern of responding on a response-dependent schedule. The results are incompatible with a response-based explanation of within-session changes in responding (e.g., fatigue), but are consistent with both reinforcer-based (e.g., satiation) and stimulus-based (e.g., habituation) explanations.

Key words: within-session patterns, variable-interval schedule, variable-time schedule, lever press, key peck, rats, pigeons

The rate of operant responding often changes within sessions, even when factors such as rate of reinforcement remain unchanged. More specifically, responding often increases to a peak and then decreases for the remainder of the session (e.g., McSweeney, Hatfield, & Allen, 1990). Within-session changes in responding are general. They occur when different species make different responses for different reinforcers delivered using different procedures (see McSweeney & Roll, 1993, for a review).

Because of their generality, within-session changes in responding may have substantial theoretical and methodological implications. Theoretically, within-session changes may pose a problem for evaluating the validity of both molar and molecular theories of operant behavior. Molar theories (e.g., Herrnstein, 1970) often use rate of responding averaged across the session as the main dependent variable. Averaging in this way overlooks orderly changes in behavior. Mo-

lecular theories (e.g., Hinson & Staddon, 1983) try to explain behavior on a moment-by-moment basis. Within-session changes in responding indicate that the relevant moment-by-moment variables are changing in ways that may be difficult to assess.

From a methodological standpoint, within-session changes in responding may complicate data interpretation. For example, it is common when changing the rate of reinforcement across conditions to change the length of the session so that the total number of reinforcers obtained during the session is held constant across conditions. However, such a procedure may produce different rates of responding between conditions in part because different portions of the within-session pattern of responding are sampled. This problem becomes more serious if different rates of reinforcement produce different within-session patterns of responding.

McSweeney (1992) demonstrated that different within-session patterns of responding occur at different rates of reinforcement. Rats pressed a lever for food pellets delivered by a multiple variable-interval (VI) VI schedule of reinforcement during a 60-min session. Response rates peaked early in the session and then decreased steeply when the rate of reinforcement was high (e.g., multiple VI 15 s

We thank Craig Parks for his editorial comments on earlier versions of this manuscript. This manuscript is based upon work supported by the National Science Foundation under Grant IBN-9403719 awarded to Frances K. McSweeney.

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VI 15 s). The within-session pattern of responding was flatter, with the peak rate of responding occurring later in the session, when the rate of reinforcement was low (e.g., multiple VI 240 s VI 240 s).

Weatherly, McSweeney, and Swindell (1995) replicated the results of McSweeney (1992) but with pigeons as subjects and with both the magnitude and rate of reinforcement being varied so that subjects received a total of 300 s of access to reinforcement per session during each condition. Response rates decreased more steeply within the session at high rates of reinforcement (e.g., multiple VI 15-s VI 15-s schedule) than at low rates of reinforcement (e.g., multiple VI 240-s VI 240-s schedule) even though subjects earned the same total amount of reinforcement. The results of this study indicate that the within-session pattern of responding is determined by the rate of reinforcement within the session.

Results reported by McSweeney, Weatherly, and Roll (1995) indicated that all reinforcers delivered within the session may help to determine the within-session pattern of responding. They studied the responding of rats and pigeons maintained by concurrent VI VI schedules in which a different kind of response produced the reinforcer in each component. During the 60-min session, rats obtained reinforcers by pressing a lever in one component and pressing a key in the other component. Pigeons obtained reinforcers by pecking a key in one component and pressing a treadle in the other component. Response rates changed similarly within sessions in the two components, regardless of whether the rates of reinforcement in the components were the same (e.g., concurrent VI 60-s VI 60-s schedules) or different (e.g., concurrent VI 15-s VI 240-s schedules). These results suggest that some combination (e.g., the sum) of reinforcers in the two components determined the pattern of responding in each component.

The present experiment was designed to determine whether delivering response-independent reinforcers would influence the within-session pattern of responding. Rats pressed a lever and pigeons pecked a key for food delivered on a VI schedule of reinforcement. The value of the VI differed across different conditions. While subjects were re-

sponding on the VI schedule, a variable-time (VT) schedule of reinforcement delivered the same reinforcer, independent of responding, at a rate equal to the VI schedule in effect for that condition (i.e., a conjoint VI VT schedule of reinforcement). If response patterns are determined by the total number of reinforcers presented, then similar patterns of responding should be observed whether subjects receive the same number of reinforcers from a simple VI schedule or from a conjoint VI VT schedule. If the pattern of responding is determined only by response-dependent reinforcers, then delivering response-independent reinforcers should not affect the within-session pattern of responding.

To test the above possibilities, the responding of subjects in the present study was compared to that previously obtained from subjects responding on simple VI schedules of reinforcement that programmed the same total number of reinforcers per session (McSweeney, Weatherly, & Swindell, 1996). The procedural details used in the present experiment were similar to those used by McSweeney *et al.* (1996), and the same pigeons served as subjects in both studies. However, the rats used by McSweeney *et al.* were advanced in age. Therefore, to ensure that enough rats would complete all the conditions of the present study, different rats were used than those used by McSweeney *et al.*

METHOD

Subjects

The subjects were 4 experimentally naive male Sprague-Dawley rats and 3 experimentally experienced homing pigeons. Subjects were obtained from and housed at the Johnson Tower Vivarium at Washington State University. The rats were approximately 90 days old at the inception of the experiment and were from the same litter. The pigeons varied in age. Subjects were housed individually and experienced a 12:12 hr light/dark cycle. The rats and pigeons were housed in different rooms. The subjects were maintained at approximately 85% of their free-feeding body weights by postsession feedings, when necessary, and by daily feedings during those days in which sessions were not conducted. The

85% weights of the rats were recalculated twice over the course of the experiment. This was accomplished by giving the rats free access to food for 5 days, during which experimental sessions were not conducted. The new free-feeding body weight of each rat was calculated from its weight on the 5th day. The 85% weights of the rats ranged from approximately 340 g at the beginning of the experiment to approximately 450 g at the end of the experiment. The 85% weights of the pigeons were determined several weeks before the beginning of the experiment. Pigeons were given free access to food for 5 days, and their 85% weights were calculated from their weights on the 5th day. The weights of the pigeons were held constant throughout the course of the experiment and ranged among pigeons from approximately 265 g to approximately 290 g. All subjects had water freely available in the home cage. Pigeons also had grit freely available in the home cage. Water was not available in the experimental chambers.

Apparatus

Rats responded in a Stoelting two-lever experimental enclosure, measuring 20 cm by 24.5 cm by 24.5 cm. An opening (5 cm by 5.5 cm), which allowed access to a 45-mg Noyes food pellet (Formula A), was centered on the front panel, 0.5 cm above the floor. A relay click accompanied the delivery of a food pellet. Two levers (4 cm by 1.5 cm) were located 2.5 cm from this opening, one on each side. The levers extended 1.5 cm into the enclosure and were 5 cm above the floor. Only the right lever was used in the present study. A force of approximately 0.25 N was required to depress the lever. A white light (2 cm diameter, 1.12 W) was located 2.5 cm above the lever, 9 cm above the floor. A houselight (2 cm diameter, 1.12 W) was located in the center of the ceiling.

Pigeons responded in a Grason-Stadler two-key experimental enclosure, measuring 27 cm by 30 cm by 29.5 cm. The keys were Plexiglas disks (2.5 cm diameter) located 23 cm above the floor and 12.5 cm from each other. Only the left key was used in the present study. It was located 6 cm from the left wall and could be transilluminated red by a 1.12-W light. A force of approximately 0.25 N was required to operate the key. Two treadles

had previously been installed, one below each key. The treadles were not used in the present study. An opening (5 cm by 4 cm) allowed access to a solenoid-operated food magazine. Reinforcers were 5-s access to mixed grain. The opening was located below the keys, 12.5 cm from the right wall and 3 cm above the floor. A houselight (1 cm diameter, 1.12 W) was located 0.5 cm from the left wall and 28 cm above the floor.

Each enclosure was housed in a sound-attenuating chamber. A ventilating fan masked outside noises. An IBM®-compatible 486 computer, connected to a MED Associates interface and running MED-PC® software, controlled the experimental events and recorded the data. It was located in an adjacent room.

Procedure

For rats, pressing the lever was shaped using the method of successive approximations. Rats were placed on the experimental procedure after each had pressed the lever more than 100 times under continuous reinforcement (i.e., each response produced a food pellet). Because the pigeons were experimentally experienced, no key-peck training was necessary.

During the first experimental condition, subjects responded on a VI 60-s schedule. A VT 60-s schedule also delivered reinforcers during the 60-min session. Reinforcers scheduled by the VI and VT schedules were delivered according to independent 25-interval series, constructed as suggested by Fleshler and Hoffman (1962). Reinforcers scheduled by the VT schedule were delivered as soon as the interval elapsed, regardless of whether a reinforcer was available but not yet delivered on the VI schedule. The houselight and the light above the lever (rats) or on the key (pigeons) were illuminated. The light above the lever or on the key was extinguished during reinforcement. Total-session and interreinforcer times were not incremented for pigeons during reinforcement.

In subsequent experimental conditions, the values of the VI and VT components of the conjoint schedule were varied, but were always equal within a condition. In all, six conjoint VI VT schedules (experimental conditions) were studied in the following order: conjoint VI 60 s VT 60 s, conjoint VI 240 s VT 240 s, conjoint VI 480 s VT 480 s, conjoint

VI 30 s VT 30 s, conjoint VI 120 s VT 120 s, and conjoint VI 15 s VT 15 s. Sessions were conducted daily, 5 to 6 days per week. Each experimental condition was conducted for a total of 30 sessions. For rats, two 7-day breaks occurred in which sessions were not conducted. On the first 5 of these days, subjects were given free access to food and new body weights were determined. Days 6 and 7 were used to deprive subjects to their new 85% weights. A break occurred during the conjoint VI 240-s VT 240-s and conjoint VI 30-s VT 30-s schedule conditions.

Data Analysis

The response patterns in the present experiment were compared to those from McSweeney *et al.* (1996). In McSweeney *et al.*'s study, rats pressed a lever and pigeons pecked a key on simple VI schedules that programmed between 15 (VI 240 s) and 480 (VI 7.5 s) reinforcers per hour, in different conditions. The combination of VI and VT schedules used in the present experiment also scheduled between 15 and 480 reinforcers per hour, in different conditions. Therefore, the response patterns in the different studies could be compared during conditions that scheduled the same number of reinforcers per hour.

Before comparing the within-session response patterns between the two studies, however, the number of reinforcers received per session during each conjoint VI VT schedule was compared to the number received during its comparable VI schedule in McSweeney *et al.*'s study. When the number of reinforcers received did not differ, the within-session patterns of responding were compared by applying analyses of variance (ANOVAs) to the percentage of total-session responses per 5-min interval in the session, using the data of individual subjects. Percentages were calculated by dividing the number of responses in a 5-min interval by the total number of responses in the entire session and then multiplying by 100%. Percentages were used because they normalize for differences in absolute rates of responding without changing other functional relations in the data. However, using percentages meant that the percentage in the 12th 5-min interval was fixed. That is, when the percentages in the first 11 5-min intervals had been determined,

the value in the 12th interval was known. Therefore, the ANOVAs on percentages were conducted using only the first 11 5-min intervals so as to avoid this nonindependence (see Keppel, 1991, for a discussion of the assumptions of the ANOVA). Data for all analyses were taken from the final five sessions for which each condition was in effect. Results were considered significant at $p < .05$.

RESULTS

Table 1 presents the overall rate of responding and the mean number of reinforcers received per session, along with the standard error of the mean (*SEM*) for each measure, for each subject and for the mean of all subjects in each conjoint VI VT condition. One-way repeated measures ANOVAs, conducted on the response rates for individual subjects, showed that the rate of responding changed significantly with changes in the schedule value for both rats, $F(5, 15) = 4.53$, and pigeons, $F(5, 10) = 11.33$. However, the direction of this change differed for rats and pigeons. Table 1 shows that the response rates for rats usually varied directly with rate of reinforcement, with the highest rates of responding usually occurring during the conjoint VI 15-s VT 15-s schedule or the conjoint VI 30-s VT 30-s schedule. Conversely, the response rates for pigeons varied inversely with rate of reinforcement, with the highest rates of responding occurring during the conjoint VI 240-s VT 240-s schedule or the conjoint VI 480-s VT 480-s schedule.

Figures 1 and 2 present, for rats and pigeons, respectively, the percentage of total-session responses during successive 5-min intervals of the session for each subject in each conjoint VI VT schedule. Responding usually changed within the session. More specifically, response rate decreased steeply when the interreinforcer interval (IRI) was short. The pattern of responding became flatter as the IRI became longer. The data in Figures 1 and 2 were analyzed by conducting one-way repeated measures ANOVAs on percentages for individual subjects. When rats served as subjects, responding changed significantly within the session during the conjoint VI 15-s VT 15-s schedule, $F(10, 30) = 21.15$, the VI 30-s VT 30-s schedule, $F(10, 30) = 8.99$, the VI 60-s VT 60-s schedule, $F(10, 30) = 4.02$, and

Table 1

The mean rate (responses per minute; R) of lever pressing (rats) and key pecking (pigeons), along with the standard error of the mean (*SEM*), for each subject and for the mean of all subjects during the final five sessions of each conjoint VI VT schedule condition. The mean number of reinforcers (*S^R*) presented per session in each condition, along with the *SEM*, is also presented. The schedule values were identical in each component of the conjoint schedule of reinforcement. The *SEMs* for the group means were calculated using the mean response rates and received reinforcers of individual subjects.

			Conjoint VI VT schedule value					
Subject			15 s	30 s	60 s	120 s	240 s	480 s
Rats	332	R	8.3	11.3	4.4	3.4	2.1	2.0
		<i>SEM</i>	0.6	0.3	0.7	1.2	0.1	0.1
		<i>S^R</i>	386.6	224.0	108.2	50.0	27.0	16.4
	333	<i>SEM</i>	7.9	1.0	4.3	3.4	2.5	1.0
		R	5.8	5.2	3.4	4.2	0.7	1.0
		<i>SEM</i>	0.3	0.7	0.5	0.9	0.1	0.1
	334	<i>S^R</i>	344.2	200.6	106.0	50.8	27.8	14.6
		<i>SEM</i>	5.6	5.5	1.8	3.2	1.7	1.2
		R	1.7	9.4	2.8	1.4	1.1	0.8
	335	<i>SEM</i>	0.6	1.0	0.7	0.6	0.1	0.1
		<i>S^R</i>	285.2	221.2	98.6	40.0	27.0	11.8
		<i>SEM</i>	16.1	3.1	5.3	3.4	1.3	1.4
	<i>M</i>	R	0.9	1.1	1.1	1.9	0.5	1.0
		<i>SEM</i>	0.1	0.2	0.3	0.7	0.1	0.1
		<i>S^R</i>	276.0	163.2	85.4	45.0	22.6	13.8
Pigeons	913	<i>SEM</i>	6.2	3.3	5.3	1.5	2.1	1.2
		R	4.2	6.8	2.9	2.7	1.1	1.2
		<i>SEM</i>	1.7	2.3	0.7	0.7	0.4	0.3
	914	<i>S^R</i>	323.0	202.3	99.6	46.5	26.1	14.2
		<i>SEM</i>	26.0	14.0	5.1	2.5	1.2	1.0
		R	3.7	10.3	20.4	12.3	50.3	46.7
	916	<i>SEM</i>	0.4	2.7	3.4	3.2	3.1	1.4
		<i>S^R</i>	292.0	161.8	99.4	53.0	26.4	14.0
		<i>SEM</i>	5.9	9.0	3.3	1.8	1.6	2.3
	<i>M</i>	R	6.2	2.1	9.1	4.4	23.0	46.1
		<i>SEM</i>	1.9	0.8	0.7	1.9	1.2	1.5
		<i>S^R</i>	288.2	148.0	94.2	43.6	27.2	14.6
	916	<i>SEM</i>	11.6	6.0	2.3	2.8	2.0	1.5
		R	5.0	11.5	48.9	25.1	58.2	47.8
		<i>SEM</i>	1.3	4.1	4.1	6.4	1.9	2.7
	<i>M</i>	<i>S^R</i>	272.0	150.0	104.4	51.6	29.4	15.4
		<i>SEM</i>	5.8	6.2	3.6	1.4	2.1	1.7
		R	5.0	8.0	26.1	13.9	43.8	46.9
	<i>M</i>	<i>SEM</i>	0.7	3.0	11.8	6.0	10.7	0.5
		<i>S^R</i>	284.1	153.3	99.3	49.4	27.7	14.7
		<i>SEM</i>	6.1	4.3	2.9	2.9	0.9	0.4

the VI 480-s VT 480-s schedule, $F(10, 30) = 2.45$, but not during the conjoint VI 120-s VT 120-s schedule, $F(10, 30) = 2.10$, and the VI 240-s VT 240-s schedule, $F(10, 30) = 1.71$. When pigeons served as subjects, responding changed significantly within the session during the conjoint VI 15-s VT 15-s schedule, $F(10, 20) = 7.48$, the VI 30-s VT 30-s schedule, $F(10, 20) = 9.05$, and the VI 240-s VT 240-s schedule, $F(10, 20) = 6.52$, but not during the conjoint VI 60-s VT 60-s schedule, $F(10, 20) = 1.23$, the VI 120-s VT 120-s sched-

ule, $F(10, 20) = 1.59$, and the VI 480-s VT 480-s schedule, $F(10, 20) = 1.13$.

Figure 3 presents the mean number of reinforcers received by all subjects per 1-hr session in the present study and in McSweeney et al.'s (1996) study as a function of the number of reinforcers programmed per hour. The results for rats were analyzed by conducting independent-samples *t* tests on the number of reinforcers received by individual subjects. No significant differences were observed, $t(6) = 2.37$, 480 reinforcers per hour;

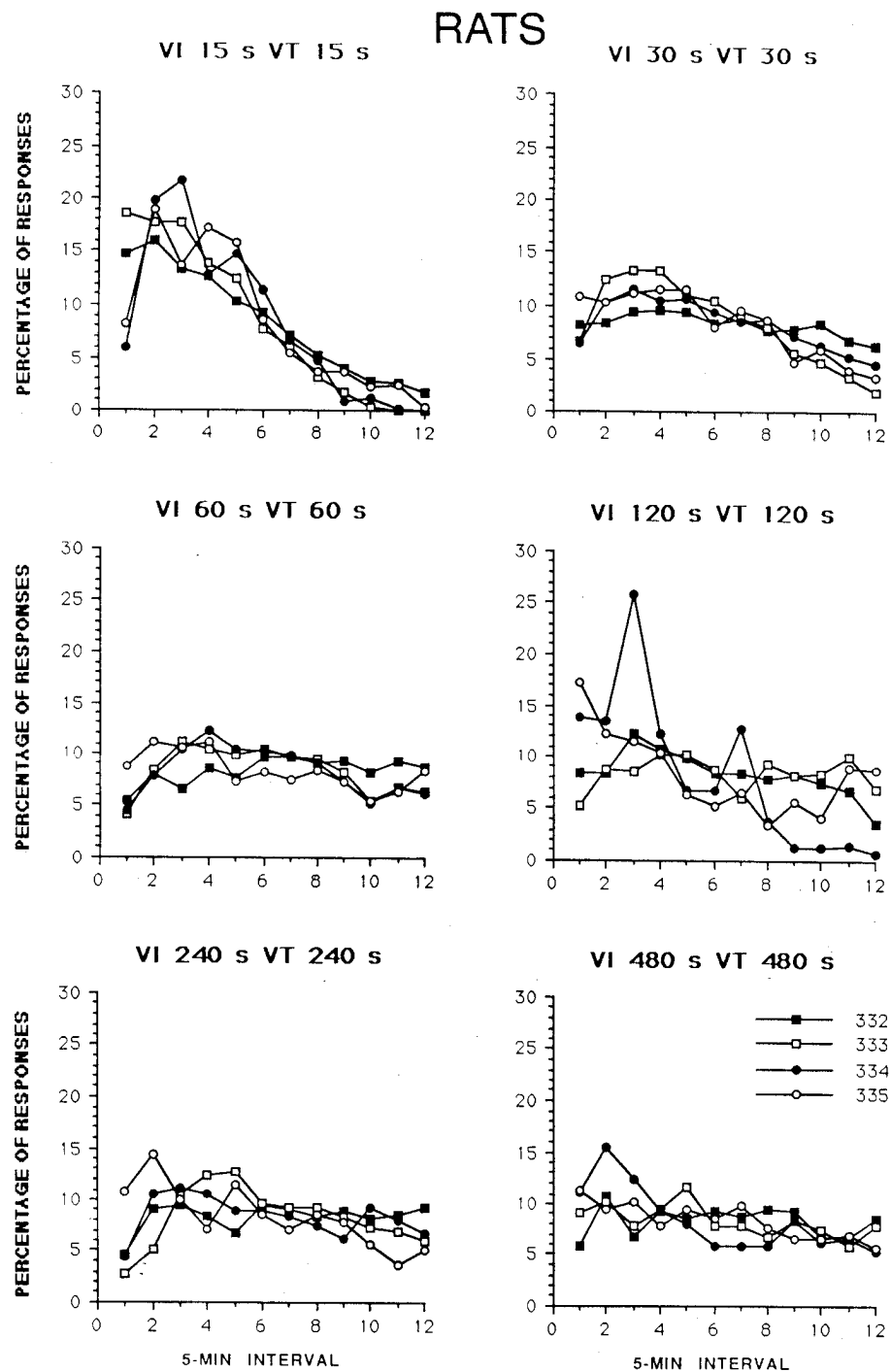


Fig. 1. The mean percentage of total-session responses during successive 5-min intervals of the session for individual rats. Each graph represents mean responding during the final five sessions of one conjoint VI VT schedule condition. The mean rates of responding presented in Table 1 can be used to convert the percentages to absolute response rates.

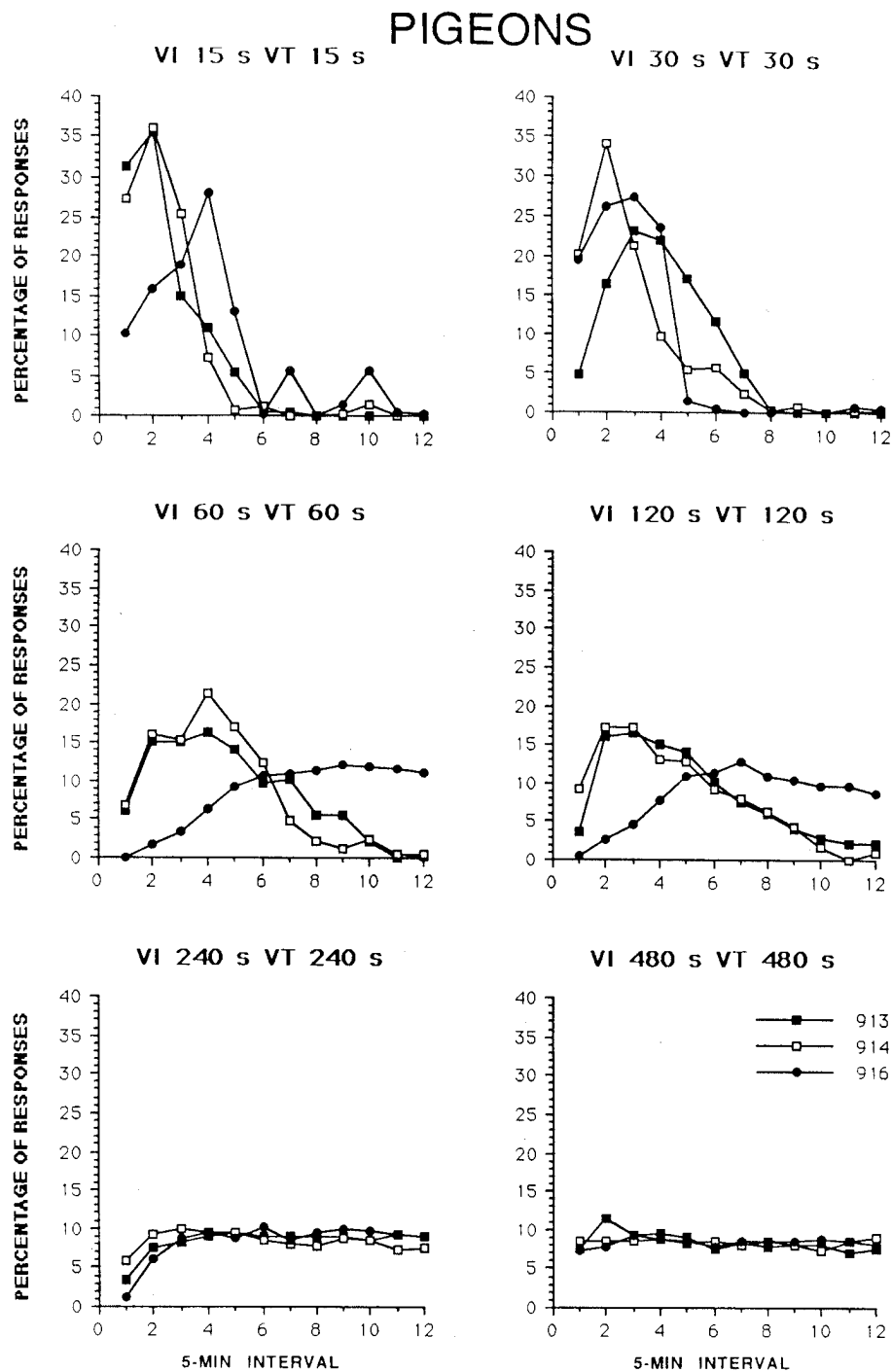


Fig. 2. The mean percentage of total-session responses during successive 5-min intervals of the session for individual pigeons. Each graph represents mean responding during the final five sessions of one conjoint VI VT schedule condition. The mean rates of responding presented in Table 1 can be used to convert the percentages to absolute response rates.

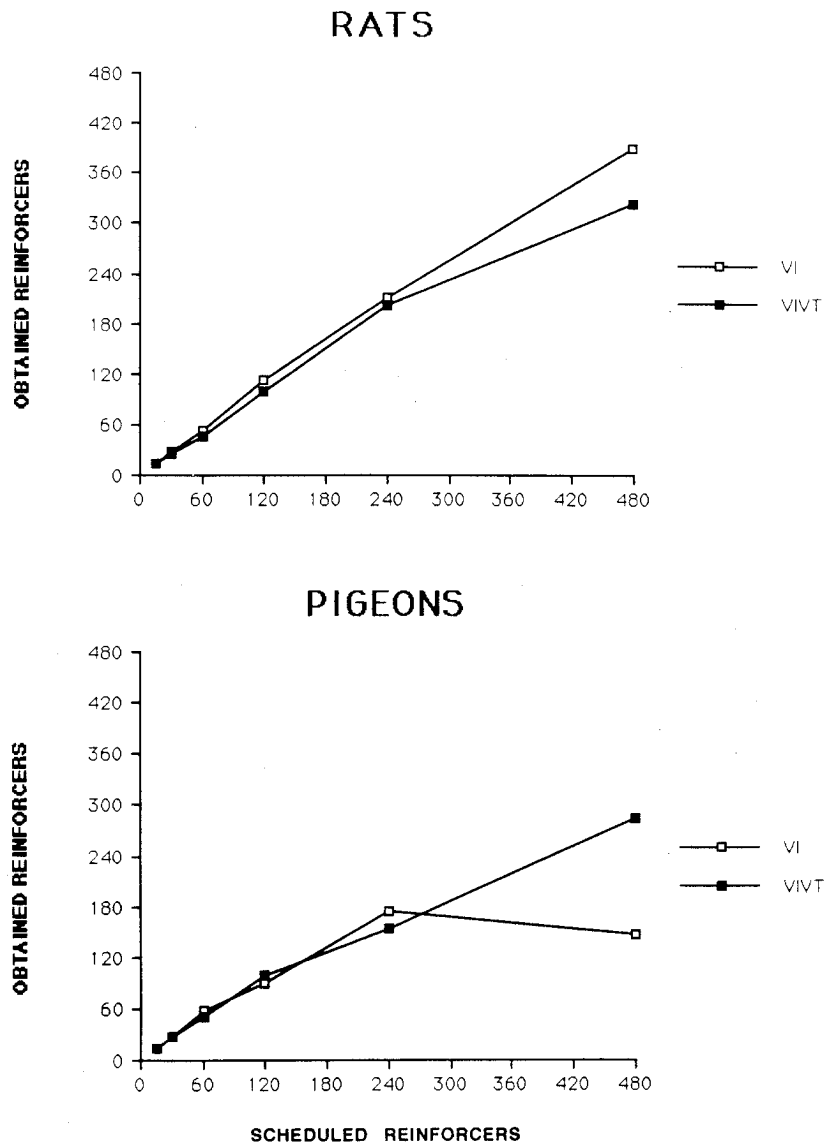


Fig. 3. The mean total number of reinforcers presented (per 1-hr session) during conditions of the present study (filled squares) and McSweeney *et al.*'s (1996) study (open squares) as a function of the programmed number of reinforcers per hour.

$t(6) = 0.60$, 240 reinforcers per hour; $t(6) = 2.13$, 120 reinforcers per hour; $t(6) = 2.21$, 60 reinforcers per hour; $t(6) = 0.60$, 30 reinforcers per hour; $t(6) = 0.83$, 15 reinforcers per hour. The results for pigeons were analyzed by conducting dependent-samples t tests on the number of reinforcers received by individual subjects. Dependent-samples t tests were used because the same subjects served in both studies. Subjects responding

on the conjoint VI 15-s VT 15-s schedule received significantly more reinforcers than when they responded on the VI 7.5-s schedule, $t(2) = 40.68$. No other significant differences were observed, $t(2) = 2.17$, 240 reinforcers per hour; $t(2) = 0.62$, 120 reinforcers per hour; $t(2) = 1.56$, 60 reinforcers per hour; $t(2) = 0.19$, 30 reinforcers per hour; $t(2) = 0.89$, 15 reinforcers per hour. Therefore, Figure 3 shows that the number of re-

inforcers received in the conditions of the present experiment were usually similar to the number received in the conditions in McSweeney et al. (1996) that scheduled the same total number of reinforcers. The only exception occurred at 480 reinforcers per hour when pigeons served as subjects.

Figures 4 and 5 present, for rats and pigeons, respectively, the mean percentage of total-session responses during successive 5-min intervals of the session in the present study and in McSweeney et al.'s (1996) study during conditions that scheduled the same total number of reinforcers per hour. The data for rats were compared by conducting two-way (Study \times Interval) mixed-model ANOVAs on the percentages of total-session responses for individual subjects. Responding changed within the session in every condition. That is, the main effect of component was always significant, $F(10, 60) = 30.01$, 480 reinforcers per hour; $F(10, 60) = 7.58$, 240 reinforcers per hour; $F(10, 60) = 6.98$, 120 reinforcers per hour; $F(10, 60) = 2.19$, 60 reinforcers per hour; $F(10, 60) = 5.50$, 30 reinforcers per hour; $F(10, 60) = 2.36$, 15 reinforcers per hour. The response patterns differed between the studies at short, but not long, IRIs. That is, a significant interaction between study and interval was observed at 480 reinforcers per hour, $F(10, 60) = 7.42$, and 240 reinforcers per hour, $F(10, 60) = 9.51$. As can be seen in Figure 4, steeper decreases in responding were observed in the present study during these conditions than in McSweeney et al.'s study. Response patterns did not differ between the studies at longer IRIs, $F(10, 60) = 1.32$, 120 reinforcers per hour; $F(10, 60) = 1.90$, 60 reinforcers per hour; $F(10, 60) = 0.29$, 30 reinforcers per hour; $F(10, 60) = 1.62$, 15 reinforcers per hour.

The results for pigeons were analyzed by conducting two-way (Study \times Interval) repeated measures ANOVAs on the percentages of total-session responses for individual subjects. The 480 reinforcers per hour conditions for pigeons were not analyzed because, as noted above, they differed in the total number of reinforcers that were received. In the conditions that were analyzed, responding usually changed within the session. The main effect of component was significant at 240 reinforcers per hour, $F(10, 20) = 13.94$,

120 reinforcers per hour, $F(10, 20) = 9.61$, and 15 reinforcers per hour, $F(10, 20) = 3.06$, but not at 60 reinforcers per hour, $F(10, 20) = 1.18$, or 30 reinforcers per hour, $F(10, 20) = 2.11$. Response patterns differed between the studies (i.e., significant interaction term) during the 240 reinforcers per hour conditions, $F(10, 20) = 5.20$, and the 60 reinforcers per hour conditions, $F(10, 20) = 2.89$, but not during the 120 reinforcers per hour conditions, $F(10, 20) = 0.22$, the 30 reinforcers per hour conditions, $F(10, 20) = 1.08$, or the 15 reinforcers per hour conditions, $F(10, 20) = 0.60$. As for rats, when significant differences were observed, responding decreased more steeply within the session during the present study than during McSweeney et al.'s (1996) study.

DISCUSSION

The present experiment extends the generality of within-session changes in responding by demonstrating that rates of responding change within the session when subjects respond on a conjoint VI VT schedule (see Figures 1 and 2). For rats, responding changed significantly within the session in four of the six conjoint VI VT schedule conditions. For pigeons, responding changed significantly within the session in three of the six conjoint VI VT schedule conditions. Furthermore, the within-session changes in responding were qualitatively similar for rats and pigeons. Response rate decreased steeply within the session when the IRI was short. Response patterns became flatter as the IRI lengthened. These changes are consistent with the results of previous studies that have found steep within-session decreases in response rate at high rates of reinforcement and flatter within-session response patterns at low rates of reinforcement (e.g., McSweeney, 1992; Weatherly et al., 1995).

The responding of the pigeons may not have changed significantly within the session during the conjoint VI 60-s VT 60-s and VI 120-s VT 120-s schedule conditions because Subject 916 displayed a different pattern of responding than did the other subjects (see Figure 2). In these conditions, Subject 916 paused at the beginning of the session, often for as long as 20 min, before emitting its first response. As a result, response rate for this

RATS

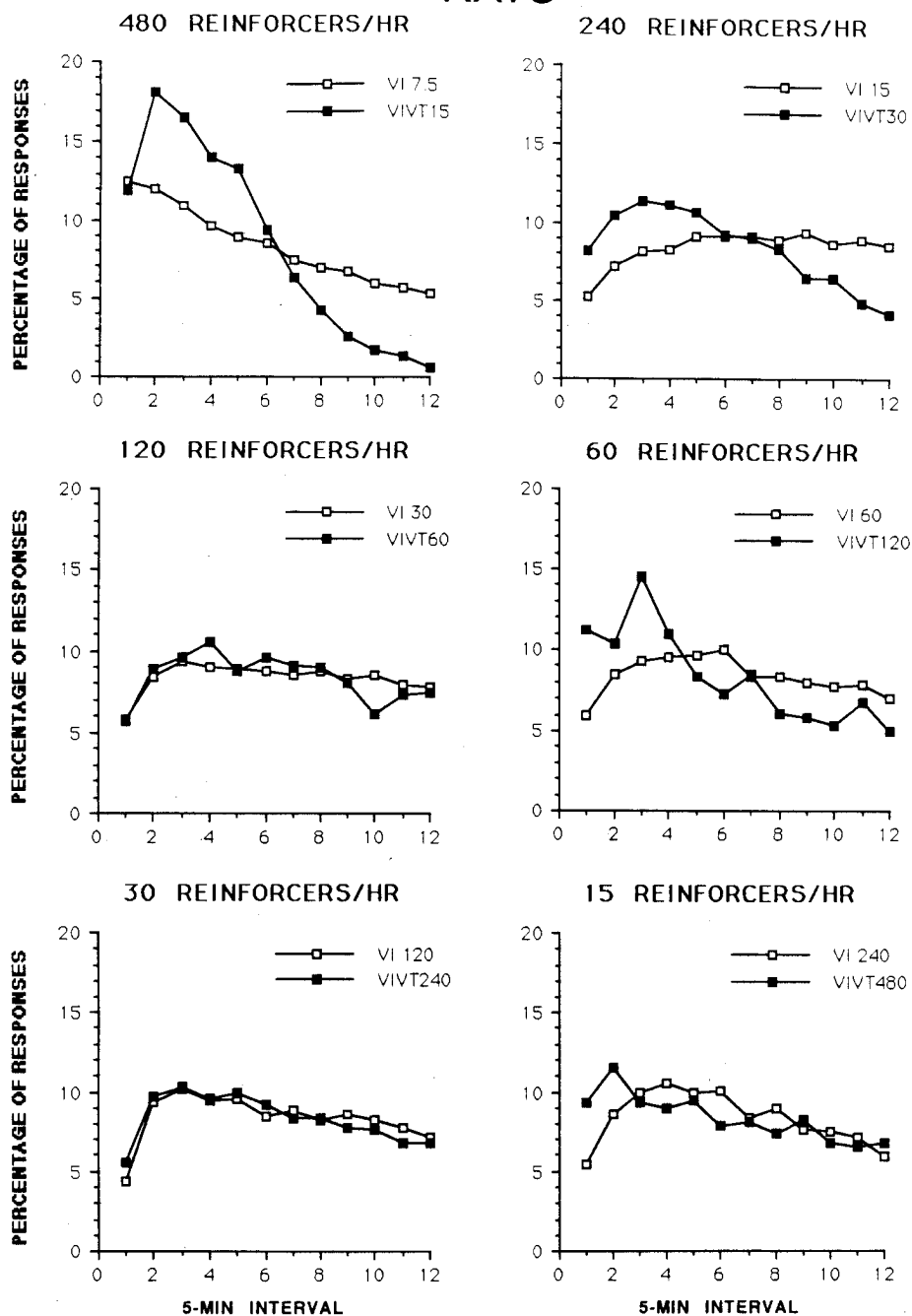


Fig. 4. The percentage of total-session responses during successive 5-min intervals of the session when rats served as subjects. Individual functions represent the mean of all subjects' responding in the present study (filled squares) or in McSweeney *et al.*'s (1996) study (open squares). Each graph presents the results for conditions that scheduled the same total number of reinforcers.

PIGEONS

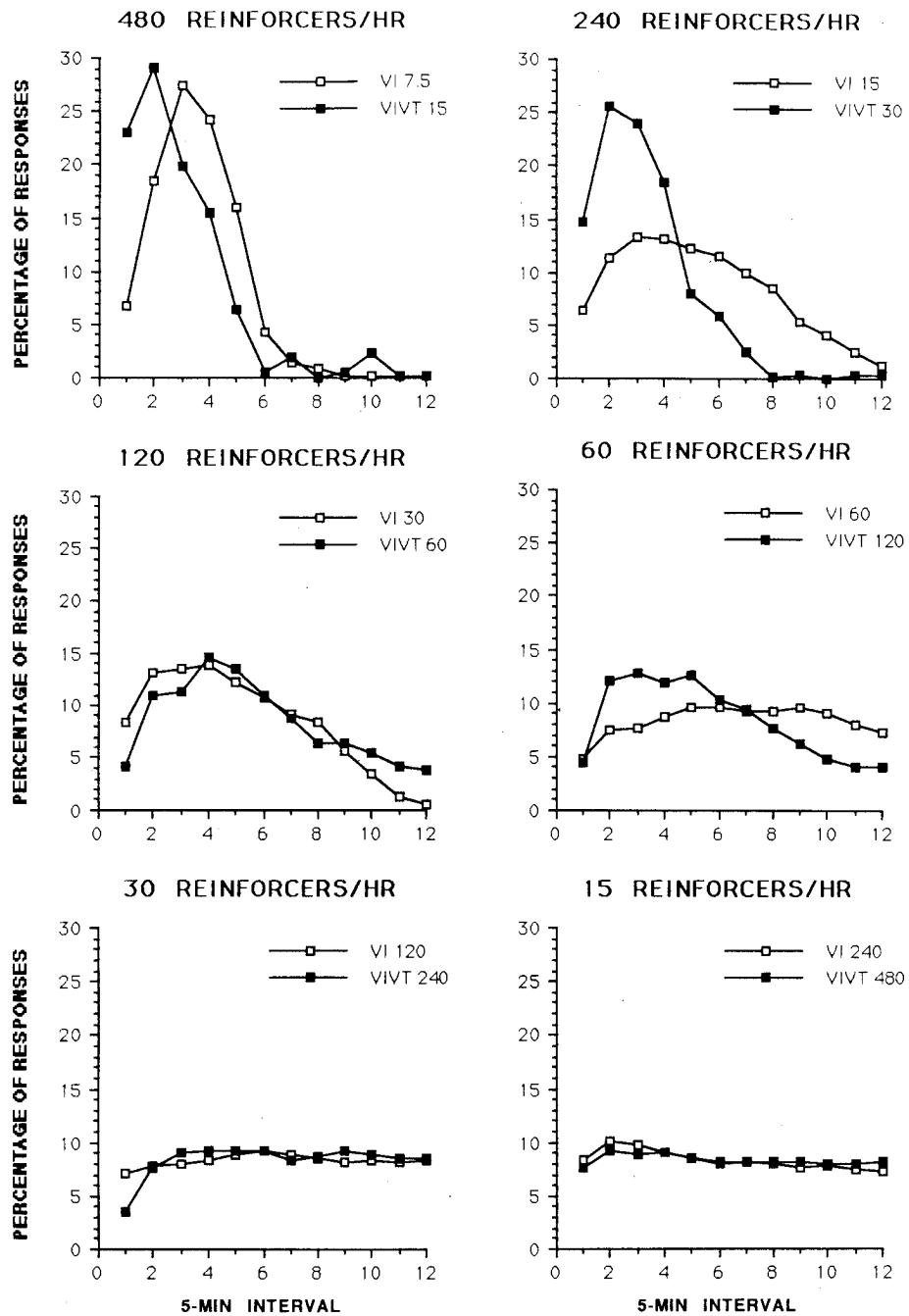


Fig. 5. The percentage of total-session responses during successive 5-min intervals of the session when pigeons served as subjects. Individual functions represent the mean of all subjects' responding in the present study (filled squares) or in McSweeney et al.'s (1996) study (open squares). Each graph presents the results for conditions that scheduled the same total number of reinforcers.

subject usually increased throughout the session. The same subject displayed similar pausing in McSweeney *et al.*'s (1996) study. Although it is not known why this subject paused before making its first response, this behavior was not produced by the absence of reinforcers, because the VT schedule delivered reinforcers throughout the session in the present study.

Taken together, the results of McSweeney *et al.* (1996) and the present study suggest that the relation between rate of responding and rate of reinforcement, averaged over the session, may differ for rats and pigeons. In both studies, the overall rate of responding by rats increased with increases in rate of reinforcement. In contrast, the rate of responding by pigeons decreased with the same increases in rate of reinforcement (see McSweeney *et al.*, 1996, Table 1; present study, Table 1). McSweeney *et al.* suggested that this difference between species might be attributed to pigeons' pausing during the session. Rats did not display such pausing. Similar pausing by pigeons was observed in the present study (see Figure 2). However, because the present study used the same pigeons as McSweeney *et al.* did, a replication of the current findings using different pigeons is needed before concluding that there is a true difference between species and that it is caused by pausing in pigeons.

The present study confirms the results of previous studies that showed that delivering response-independent reinforcers decreases the overall rate of responding (e.g., Cohen, Riley, & Weigle, 1993; Lattal, 1995). For both rats and pigeons, rates of responding were almost always lower on the conjoint VI VT schedule than on the simple VI schedule that programmed the same number of reinforcers. This suppression of responding was more pronounced for rats than for pigeons. Across the six conditions in the present study and that of McSweeney *et al.* (1996) that programmed the same number of reinforcers, the overall rate of responding of rats in the present study averaged 22.5% of that observed by McSweeney *et al.* The overall rate of responding of pigeons in the present study averaged 47% of that observed by McSweeney *et al.* in comparable conditions. There are several possible reasons for this potential difference between species. First, the pigeons

had previously responded on VI schedules; the rats had not. This possibility could be tested by repeating the present procedure, but first allowing rats to respond on simple VI schedules. Second, a stimulus-reinforcer contingency (e.g., Brown & Jenkins, 1968) may have contributed to the responding for pigeons. That is, response rates of pigeons may be comprised of both emitted and elicited key pecks. This explanation seems unlikely, however, because the light on the key did not differentially signal reinforcers in the present procedure. If elicited pecks were contributing to the responding for pigeons, then repeating the present procedure and using a signal key (e.g., Keller, 1974) to signal the delivery of reinforcers should suppress the rate of responding of pigeons to the level displayed by rats.

Even though overall rates of responding differed between VI and conjoint VI VT schedules that delivered the same overall rates of reinforcement, different within-session patterns of responding were not usually observed. When different within-session patterns were observed, they occurred at high, not at low, rates of reinforcement. Responding during conjoint VI VT schedules decreased more steeply within the session at high rates of reinforcement than did responding during simple VI schedules. Finding such differences at short IRIs is not consistent with the idea that the simple arithmetic sum of response-dependent and response-independent reinforcers determines the within-session pattern of responding during those schedules. However, finding that response patterns did not differ at long IRIs indicates that response-independent reinforcers may help to determine the within-session pattern of responding at low rates of reinforcement.

Although the present study cannot determine why the response patterns presented in Figures 4 and 5 differed only at short IRIs, such results are not unprecedented. McSweeney, Weatherly, and Swindell (1995) studied rats pressing a key or a lever for water reinforcers delivered by a multiple VI VI schedule during a 60-min session. The rate of reinforcement was varied from a multiple VI 15-s VI 15-s schedule to a multiple VI 240-s VI 240-s schedule in different conditions. McSweeney, Weatherly, and Swindell (1995)

found that the within-session pattern of key pressing by rats was similar to the within-session pattern of lever pressing at low rates of reinforcement. The pattern of key pressing differed from that of lever pressing, however, at high rates of reinforcement. Future research will need to determine why the type of response (e.g., key vs. lever pressing) and the schedule that provided reinforcers (e.g., a simple VI schedule vs. a conjoint VI VT schedule) produced different within-session patterns of responding at high, but not at low, rates of reinforcement.

The present results are incompatible with explanations for within-session changes in responding that attribute the changes to the act of responding (i.e., warm-up followed by fatigue). If the within-session changes in responding were caused by warm-up followed by fatigue, then responding should have peaked early in the session and decreased steeply when subjects responded at higher rates. That is, warm-up and fatigue should occur more rapidly when response rates are high than when they are low. Two aspects of the present results are inconsistent with this prediction. First, the highest rates of responding were observed at the highest rates of reinforcement for rats but at the lowest rates of reinforcement for pigeons (see Table 1). Nevertheless, response rates peaked early in the session and declined steeply at high rates of reinforcement for both species. Second, as discussed above, subjects responded more slowly on conjoint VI VT schedules than on the simple VI schedules used by McSweeney et al. (1996). However, the present response patterns were not flatter than those observed by McSweeney et al. On the contrary, response patterns usually did not differ between conjoint VI VT and simple VI schedules that provided the same total number of reinforcers. When differences were observed, the within-session decreases in responding were more, not less, steep in the present study than in McSweeney et al.'s study.

The present results are somewhat, but not entirely, consistent with the idea that within-session decreases in responding are produced by satiation. Responding decreased more steeply as more food was delivered, as would be expected if satiation occurred. However, the within-session pattern of responding was not always similar for VI (McSweeney et al.,

1996) and conjoint VI VT schedules (present study) that delivered the same number of reinforcers. Similar response patterns should have been observed in conditions that delivered the same amount of food if satiation were the sole determinant of the within-session pattern of responding. The results of several other studies also question whether variables that should alter satiation alter within-session patterns of responding (e.g., McSweeney & Johnson, 1994; Roll, McSweeney, Johnson, & Weatherly, 1995; Weatherly et al., 1995). For example, Roll et al. (1995) varied the caloric density of the reinforcer from 0 to 15.2 calories per gram, varied the deprivation level of the subjects from 75% to 95% of their free-feeding body weights, and varied the size of the reinforcer by up to a factor of five, in different experiments. The within-session pattern of responding was altered when the size of the reinforcer was increased by a factor of five over that delivered during baseline, but not when it was increased by a factor of three. The other manipulations did not change the within-session pattern of responding.

The present results are also somewhat, but not entirely, consistent with the idea that within-session changes in responding are caused by sensitization-habituation to the reinforcer. The changes in behavior produced by presenting a stimulus repeatedly or for a long period of time have been well documented (e.g., Thompson & Spencer, 1966). These changes share many similarities with within-session changes in operant responding. Habituation occurs in many species, as do within-session changes in responding (see McSweeney & Roll, 1993). Decreases in responding to a stimulus (habituation) often begin only after an initial increase in responding (sensitization; Groves & Thompson, 1970), just as the rate of operant responding often increases and then decreases within a session (McSweeney & Hinson, 1992). Habituation often occurs more rapidly when stimuli are presented more frequently (e.g., Thompson & Spencer, 1966). Within-session response rate also decreases more steeply as reinforcers are presented more frequently (e.g., McSweeney, 1992; Weatherly et al., 1995; the present study). However, for sensitization-habituation to explain the different within-session patterns of responding for VI

and conjoint VI VT schedules at high rates of reinforcement, it would have to be assumed that subjects were habituating to some aspect of the response–reinforcer relation. This relation differs between VI and conjoint VI VT schedules, and the differences might be more pronounced when reinforcers are delivered at higher rates.

REFERENCES

- Brown, P., & Jenkins, H. M. (1968). Autoshaping of the pigeon's key peck. *Journal of the Experimental Analysis of Behavior*, 11, 1–8.
- Cohen, S. L., Riley, D. S., & Weigle, P. A. (1993). Tests of behavior momentum in simple and multiple schedules with rats and pigeons. *Journal of the Experimental Analysis of Behavior*, 60, 255–291.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 5, 529–530.
- Groves, P. M., & Thompson, R. F. (1970). Habituation: A dual process theory. *Psychological Bulletin*, 40, 385–422.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, 13, 243–266.
- Hinson, J. M., & Staddon, J. E. R. (1983). Hill-climbing by pigeons. *Journal of the Experimental Analysis of Behavior*, 39, 25–47.
- Keller, K. (1974). The role of elicited responding in behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 21, 249–257.
- Keppel, G. (1991). *Design and analysis: A researcher's handbook*. Englewood Cliffs, NJ: Prentice Hall.
- Lattal, K. A. (1995). Contingency and behavior analysis. *The Behavior Analyst*, 18, 209–224.
- McSweeney, F. K. (1992). Rate of reinforcement and session duration as determinants of within-session patterns of responding. *Animal Learning & Behavior*, 20, 160–169.
- McSweeney, F. K., Hatfield, J., & Allen, T. M. (1990). Within-session responding as a function of post-session feedings. *Behavioural Processes*, 22, 177–186.
- McSweeney, F. K., & Hinson, J. M. (1992). Patterns of responding within sessions. *Journal of the Experimental Analysis of Behavior*, 58, 19–36.
- McSweeney, F. K., & Johnson, K. S. (1994). The effect of time between sessions on within-session patterns of responding. *Behavioural Processes*, 31, 207–218.
- McSweeney, F. K., & Roll, J. M. (1993). Responding changes systematically within sessions during conditioning procedures. *Journal of the Experimental Analysis of Behavior*, 60, 621–640.
- McSweeney, F. K., Weatherly, J. N., & Roll, J. M. (1995). Within-session changes in responding during concurrent schedules that employ two different operanda. *Animal Learning & Behavior*, 23, 237–244.
- McSweeney, F. K., Weatherly, J. N., & Swindell, S. (1995). Within-session changes in key and lever pressing for water during several multiple variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 64, 75–94.
- McSweeney, F. K., Weatherly, J. N., & Swindell, S. (1996). Within-session changes in responding during variable interval schedules. *Behavioural Processes*, 36, 67–76.
- Roll, J. M., McSweeney, F. K., Johnson, K. S., & Weatherly, J. N. (1995). Satiety contributes little to within-session decreases in responding. *Learning and Motivation*, 26, 323–341.
- Thompson, R. F., & Spencer, W. A. (1966). Habituation: A model phenomenon for the study of neuronal substrates of behavior. *Psychological Review*, 73, 16–43.
- Weatherly, J. N., McSweeney, F. K., & Swindell, S. (1995). On the contributions of responding and reinforcement to within-session patterns of responding. *Learning and Motivation*, 26, 421–432.

Received July 24, 1995
Final acceptance May 29, 1996